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onset of rigor exaggerated the condition existing prior to death and the animal stiffened in the characteristic postures. This follows the rule for rigor mortis, that the more strongly acting muscles contract more strongly after death. This fact lends additional proof for the tonus theory of the tropisms.

Conclusion.—These experiments remove, in our opinion, the last doubt that the motions of animals to or from a source of light are due to an influence of the light on the tension of muscles of different sides of the body whereby the animal is automatically carried to or from a source of light.

[1] Loeb, J., *Würzburg, Sitz-Ber. physik.-med. Ges.*, 1888; *Der Heliotropismus der Tiere und seine Übereinstimmung mit dem Heliotropismus der Pflanzen*, Würzburg, 1889.

[2] Bancroft, F. W., *J. Exp. Zool., Wistar Inst., Philadelphia*, **15**, ,1913, (383).

[3] Loeb, J., and Maxwell, S. S., *Arch. ges. Physiol. Bonn*, **63**, 1896, (121).

[4] Loeb, J., and Garrey, W. E., *Ibid.*, **65**, 1896, (41).

[5] Loeb, J., *The Organism as a Whole*, New York, 1916, pp. 257–259.

[6] Holmes, S. J., *J. Comp. Neur. and Psychol., Wistar Inst., Philadelphia*, **15**, 1905, (305).

[7] Parker, G. H., *Mark Anniversary Volume*, 1903, (453).

[8] Mast, S. O., *Light and the Behavior of Organisms*, 1911.

[9] Moore, A. R., and Kellogg, F. M., *Biol. Bull., Wood's Hole, Mass.*, **30**, 1916, (131).

CHANGEABLE COLORATION IN BRACHYURA

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Communicated by A. G. Mayer, September 10, 1917

Although changes in coloration have been observed commonly in crustacea, only two recorded cases appear to refer to Brachyura. Fritz Müller reported to Darwin[1] that the male of a Brazilian species of *Gelasimus* is subject to rapid and remarkable changes in appearance. R. P. Cowles[2] has also described changes in color in *Ocypoda arenaria* Say, which he believes are in the main, if not entirely, dependent upon changes in the intensity of the light and variations in the temperature to which the creatures are exposed. It would seem, however, that crabs are able at least to change their shade much more commonly than recorded observations would indicate and that other factors than those suggested may determine their coloration at a given moment.

Portunus depressifrons Stimp., *Callinectes ornatus* Ord. and *C. marginatus* A. M.-Edw. display striking changes in coloration under certain conditions. Others less obvious or less closely studied have been noted too in *Portunus spinicarpus* Stimp. and *P. sayi* Gibbes and in

Euryplax nitida Stimp., all of which as well as those mentioned above have perhaps been overlooked because they are much less apparent in mature than in immature specimens. It is also clear that in *O. arenaria* as well as in the six species last enumerated, the shade of the substratum plays a very important part in determining that of individuals resting upon it, since in each within a few minutes, usually less than ten, at temperatures commonly prevailing in the laboratory it is possible to reverse the shade of the two members of an adapted pair simply by transferring each to the dish occupied by the other.

Light colored crabs, essentially white ones, may be cooled in white dishes from temperatures between 30° and 35°C. to 12° and be completely paralyzed by the cold without changing in the least in shade. Crabs whose shade is adjusted to that of light and dark colored dishes respectively may be transposed at a temperature at least as low as 16°C. and have their coloration reversed as definitely as under warmer conditions. Cool crabs in dark dishes may be heated to approximately 35°C. before they commence to show any effect of the treatment. At higher temperatures, which vary in individual cases, they are blanched. At such temperatures it is also impossible to induce darkening, or at least the development of a distinct pattern, by transposing a light crab to a dark dish. Hence it is apparent that temperature is not the basic factor concerned in the matter, but merely one that limits adaptive color changes in *Ocypoda* near the upper level at which it is able to survive. It is possible, indeed, that the very appearance of heat-blanching indicates the abnormality of the situation, for, regardless of the shade of the substratum, a similar effect follows when the water in which the crabs are is charged artificially with CO_2.

The degree to which *Ocypoda's* coloration is independent of temperature may be demonstrated most strikingly in a single experiment by transposing specimens which have been standing in cold white dishes and warm black ones respectively. In a specific instance the coloration of two crabs was reversed without that one which was turning from dark to light ever becoming warmer than 17°C., or the other cooler than 35°. Equality of shade was attained in twenty-nine and complete reversal in about fifty minutes. Thus it is plain that temperature is so much less effective than the shade of the underlying bottom in determining coloration that the latter is able to induce adaptive changes in opposition to Cowles's laws in the face of a temperature difference of not less than 18°C. The time relation established, however, does not represent the minimum required to effect the change, since the water in the dark dish was for a time above the temperature at which heat-blanching appears, and the darkening of the crab in it was therefore delayed.

It does not seem to be true, as has been suggested by Dr. Cowles, that the "blanching of individuals on the sands of Loggerhead Key is probably due to high temperature alone," or that during a large part of the time Ocypoda would be heat-blanched rather than adaptively colored. He observed that water standing outside the laboratory was heated to 45°C., at which temperature experiment shows that the substratum exercises a negligible effect in determining the crabs' coloration. Even higher temperatures than that recorded may occur, but this fact has only a slight bearing upon the matter at issue, for this excessive heat does not characterize the creatures' environment when they are exposed.

The animals live and feed largely in the zone below high water mark, where actual observation twice showed a temperature of 39°C. when the same thermometer lying flat in the same way on the sand 25 feet above it registered 49° and 45° respectively on the two occasions. It may also be demonstrated readily by raising the instrument half an inch on crotched sticks that the temperature prevailing at the level at which an active crab's body would actually be is considerably lower than on the sand, being 37° and 36.5° in the two cases cited. That is to say, at the hottest time in the day the temperature throughout the normal range of active crabs is very little above the minimum at which heat-blanching occurs. But at these times very few crabs are out of their burrows: five were digging them or standing idly in their mouths in the first case and only one in the second, while none at all were moving about freely over the sand where dozens might be seen both earlier and later in the cooler parts of the day. It is clear, therefore, that, unless their reactions to air and water temperatures are not the same, when the animals are actually exposed to the attacks of enemies, temperature is not sufficiently high to inhibit the effect of the substratum in inducing adaptive color changes which might reduce their conspicuousness.

So far it is apparent that the inference that adaptive color changes occur in the species mentioned rests wholly upon the demonstration of their ability to effect such changes in the laboratory. Similar adjustments are made, however, under natural conditions. It was, indeed, observation of the fact that, as one walks along a beach on which there is striking contrast between the dark and light patches covered by shallow water, the individual young *Callinectes marginatus* and *ornatus* that dart away from under foot differ in shade according as they start up from one or the other, that attracted attention to the possibility that such relations exist as have been reported in this article.

There is then every indication that further study will show that the colors of crabs and their capacity to change them vary from species to species according to the same general rules that appear to prevail among fishes.[3] But if in two groups of animals so widely separated the same laws of coloration prevail, and if the observed facts point so unanimously to the concealing function of coloration in each, it becomes increasingly improbable that other laws prevail as extensively as has been supposed among other animals, and increasingly evident that adaptation of the organism to its environment is one of the most striking of natural phenomena.

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[1] Darwin, C., *Descent of Man*, Chap. 9.

[2] Cowles, R. P., *Washington, Carnegie Inst., Pub.*, No. 103, 1908, (1-41).

[3] Longley, W. H., *J. Exp. Zoöl., Wistar Inst. Philadelphia*, 23, 1917, (536-601).

THE EQUILIBRIUM OF TORTUGAS SEA WATER WITH CALCITE AND ARAGONITE

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Communicated by A. G. Mayer, August 30, 1917

The question of the solubility of calcite and aragonite in sea water is a matter of interest in relation to the geology of limestone and dolomite. Murray and Hjort[1] maintain that sea water is so complicated a mixture that the solubility of $CaCO_3$ cannot be calculated with certainty (from the law of mass action) but that the experiments of Anderson and of Cohen and Rahen show that sea water is saturated with calcite. They add, (p. 181) that dolomite is less soluble than calcite in carbonated waters. Their book summarizes observations showing that calcium carbonate is precipitated in shallow tropical waters, but that even shells are dissolved in the red clay bottoms of the depths.

Mayer[2] placed pieces of *Cassis* shell in sea water for more than a year and found them to maintain their weight within about $\frac{1}{10}$ of 1%. The precipitation of $CaCO_3$ at Tortugas was studied by T. Wayland Vaughan, R. B. Dole, and G. H. Drew.[3] Drew observed that a denitrifying bacillus, *Pseudomonas calcis*, obtained from the sea water, was capable of changing calcium nitrate to calcium carbonate in culture media and supposes a similar process to occur in sea water. Since Vaughan has observed that calcium carbonate is constantly precipitating at Tortugas, Drew's hypothesis necessitates the presence of an appreciable amount of nitrates or nitrites, and I have attempted to determine them.